RESPONSE DUE TO HEAVY AIRCRAFT TAKEOFF: ADVANCED MODELING COMPARING SINGLE-TIRE AND DUAL-TANDEM GEAR

Jaime A. Hernandez,
PhD Candidate

Imad L. Al-Qadi, Phd, PE, Dist.M.ASCE
Founder Professor of Engineering and ICT Director

University of Illinois at Urbana-Champaign

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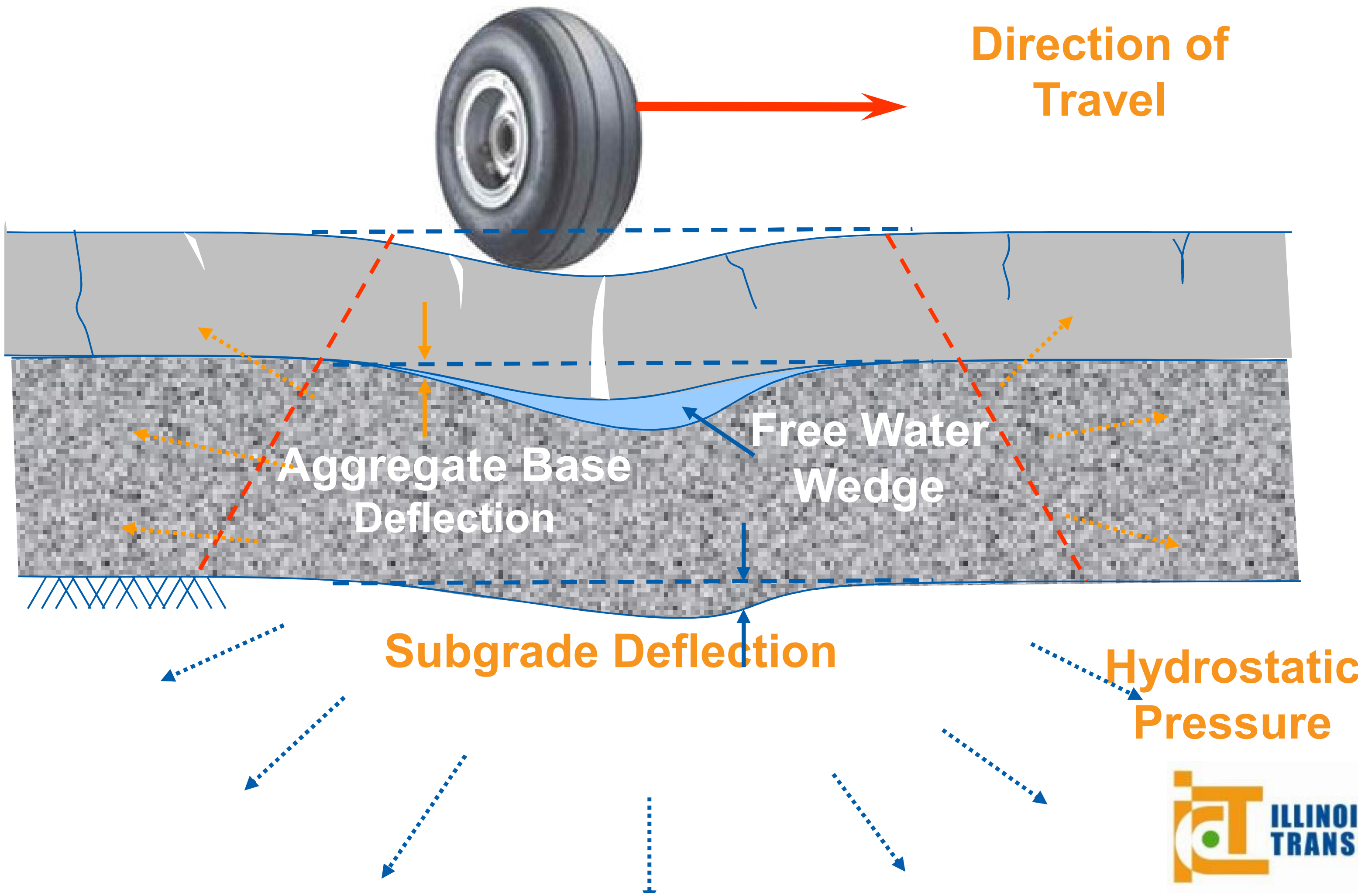
Loaded Flexible Pavement



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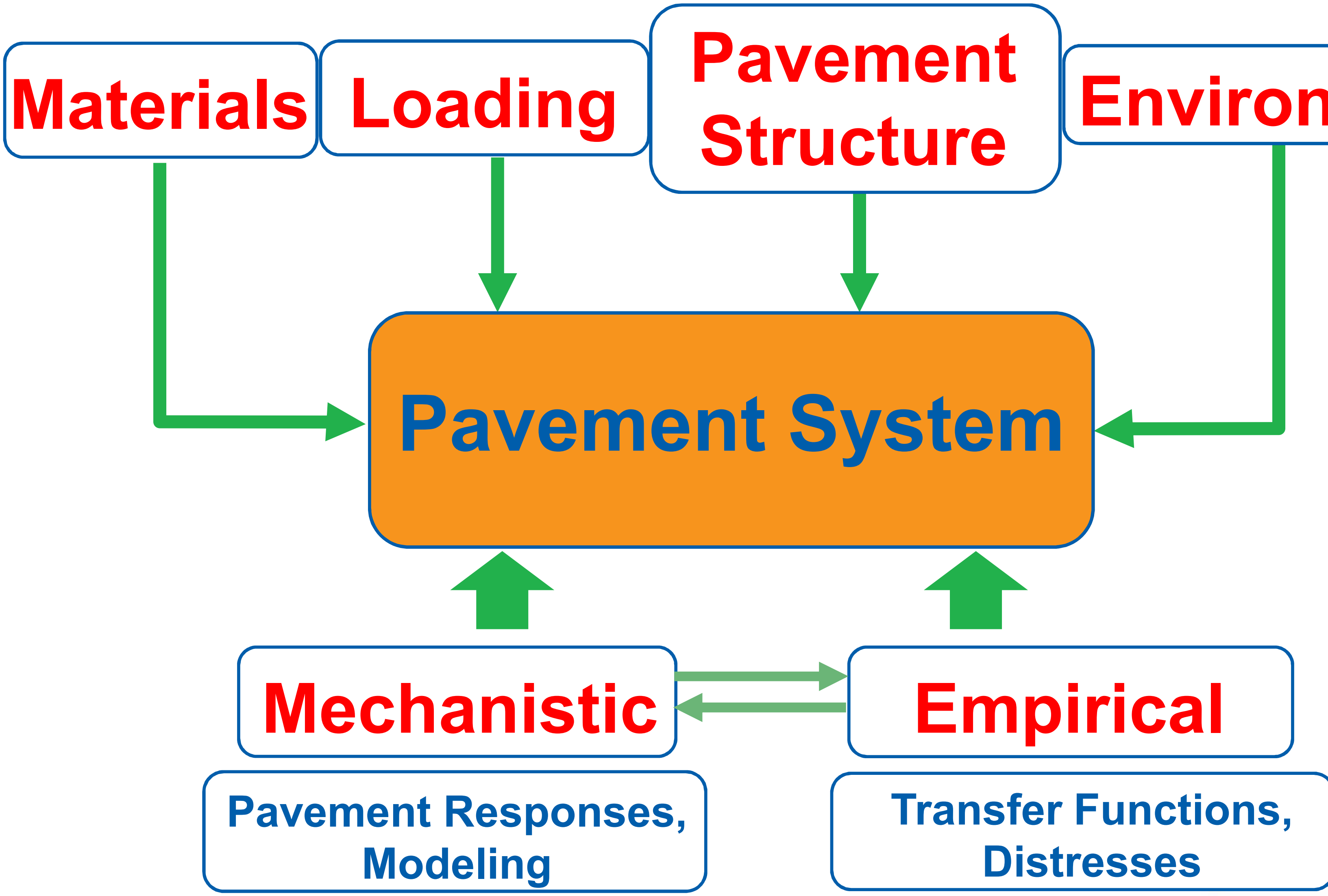
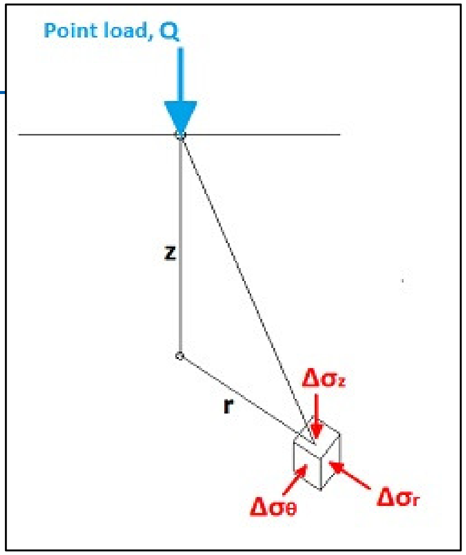
Pavement Design

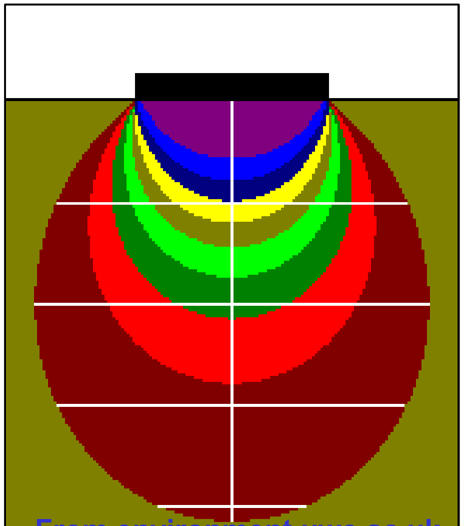


ACN-PCN

- Based on Boussinesq solution
  - Material assumed as elastic homogeneous
  - Solution for half space subjected to a point load
    - By integration another loading cases can be obtained
  - Applicable to multiple layers if modulus ratio is close to 1 or need to be adjusted



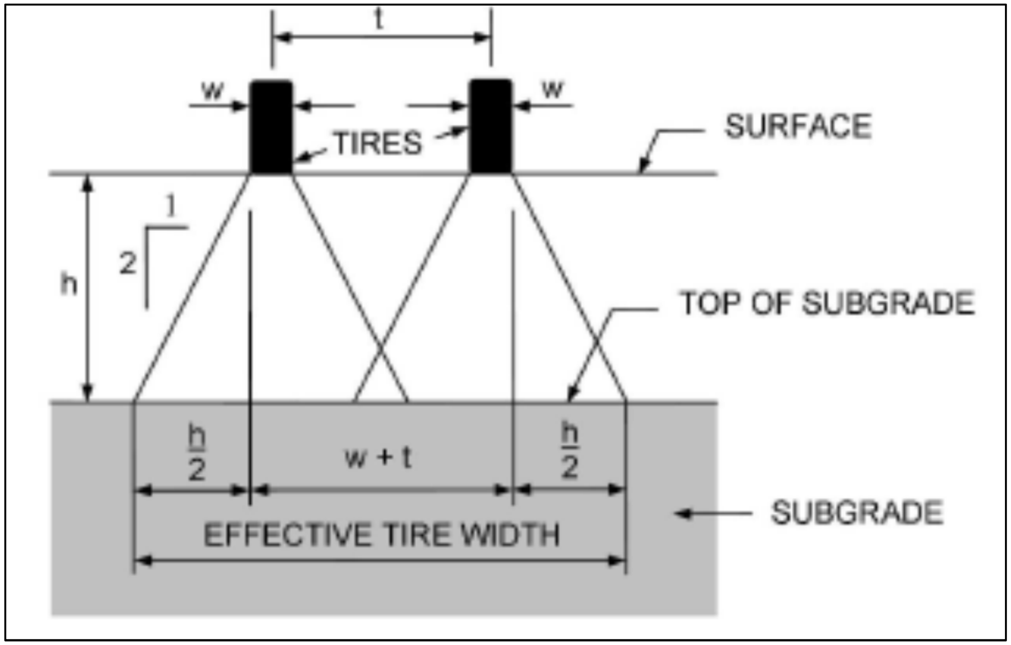
From casio-fx.com



From environment.uwe.ac.uk

Gear Interaction

- Gear interaction effect is based **on effective tire width**
- Effect of **full gear** on responses not considered directly (e.g. 3 duals in tandem)



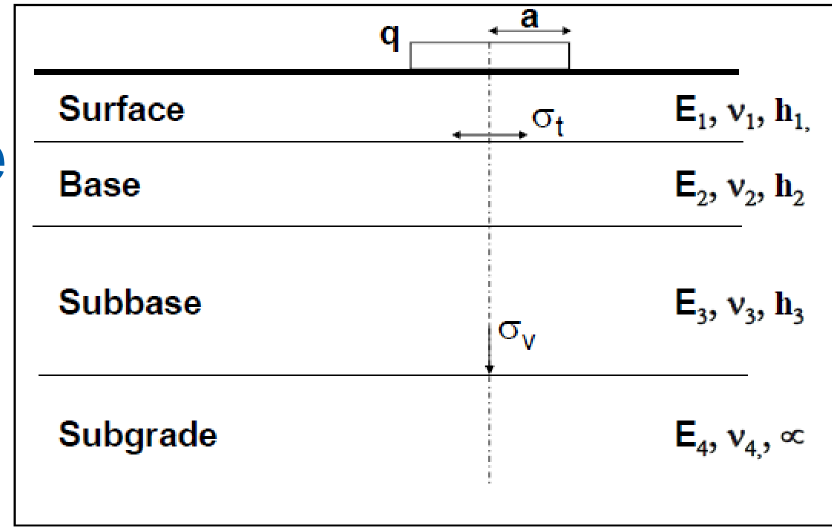
FAA Advisory Circular 150/5320-6E

FAA Design Assumptions

- Design for 20 years with no maintenances
- Mixed aircraft traffic
- Cumulative damage factor: based on tensile strain at bottom of AC and vertical strain on subgrade only
- Pavement responses: layered elastic theory

Layer Elastic Theory (FAARFIELD)

- Linear elastic materials
- Full continuity at interface
- Pavement layer: weightless and infinite in horizontal direction



- Subgrade: infinite in both directions
- Circular contact area with uniform vertical contact stresses

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Actual Behavior

Materials

- Viscoelastic and viscoplastic AC
- Stress-dependent anisotropic unbounded materials

Loading

- Dynamic load
- Irregular contact area
- 3D non-uniform contact stresses
- Gear Interaction

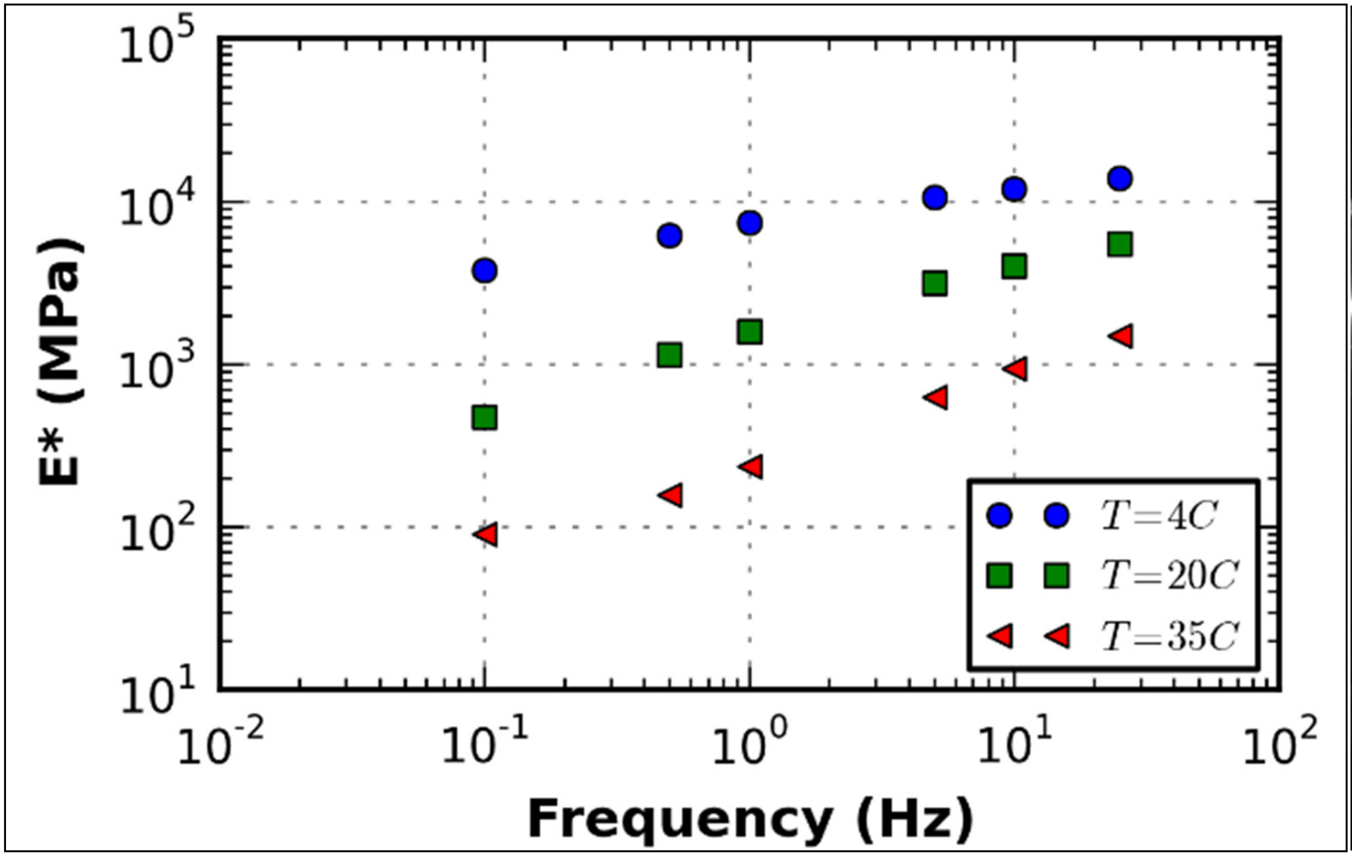
Pavement Structure

- Frictional behavior between layers (Coulomb, elastic stick)

ADVANCED FINITE ELEMENT MODELING

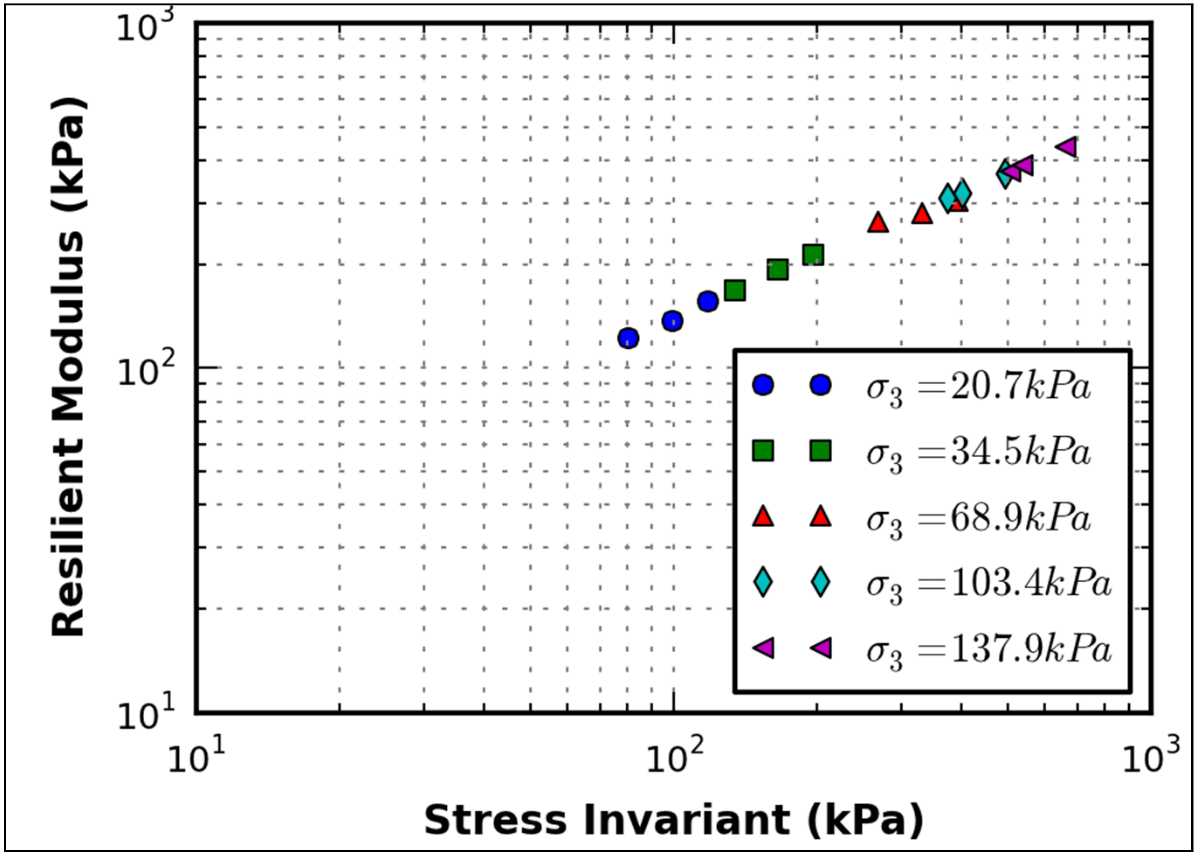
Viscoelastic AC

- Modulus of AC depends on loading time and temperature (*it is not linear elastic*)



Unbound Material

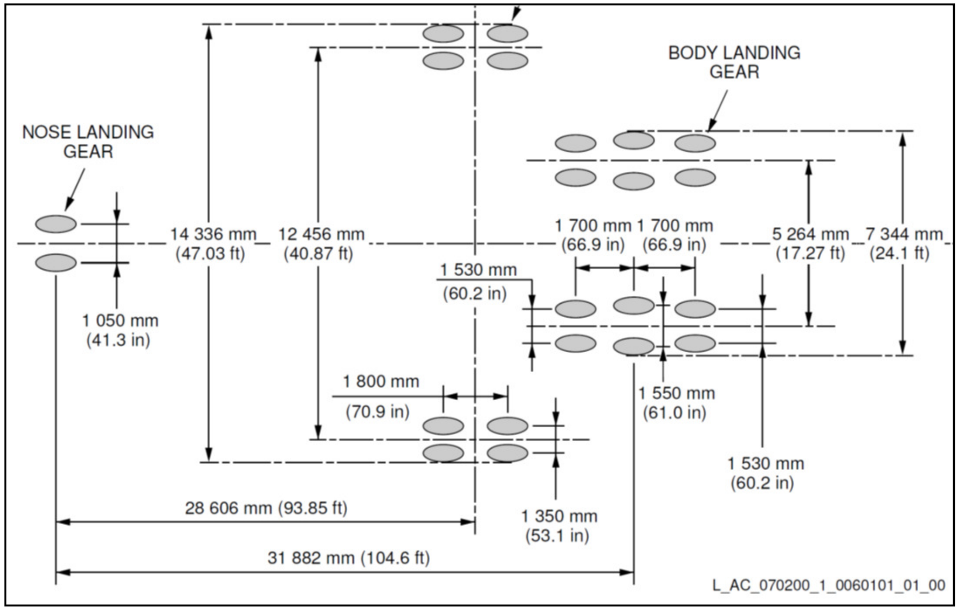
- Resilient modulus depends on **stress level** and **direction** (*it is not linear elastic*)



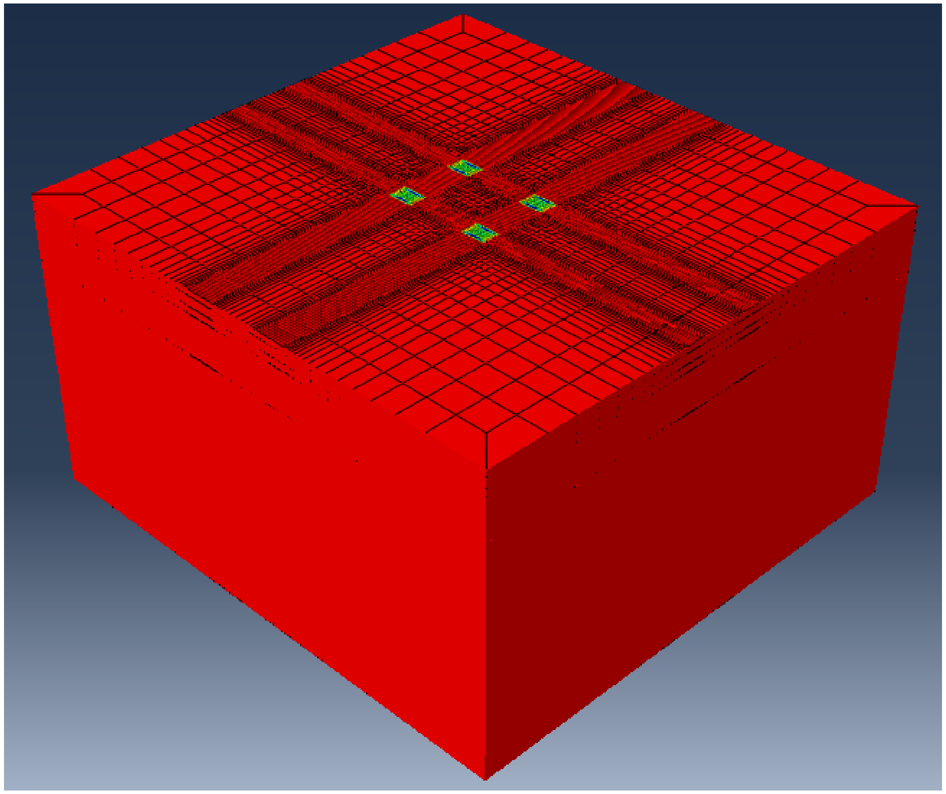
Aircraft Loading

- Moving load *(it is not stationary)*
- Loading amplitude continuously changes
- Dynamic tire force is excited by pavement irregularities *(it is not static)*
- High tire inflation pressure and load
- Gear interaction

Heavy Load Modeling: Airbus A-380



Landing Gear



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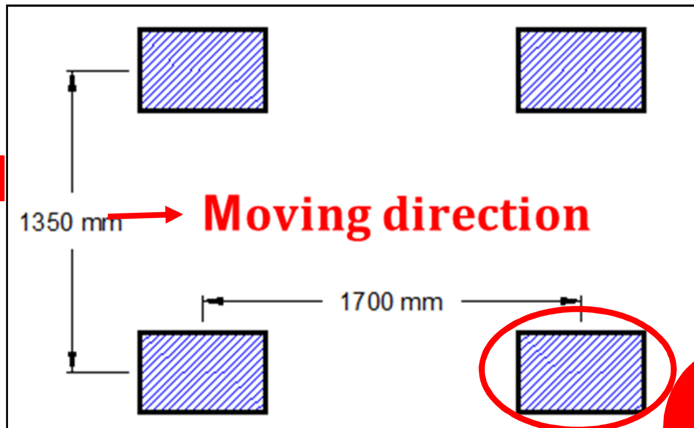
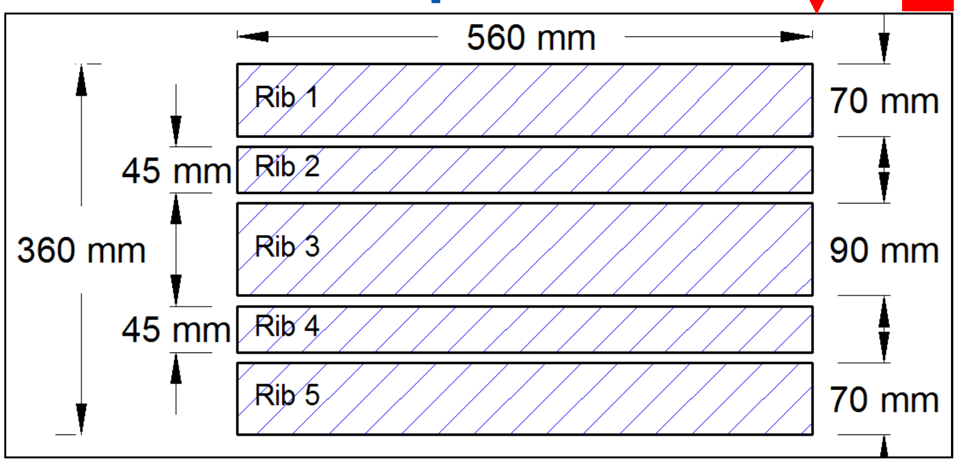
Loading – Stress Distribution

- Gear configurations

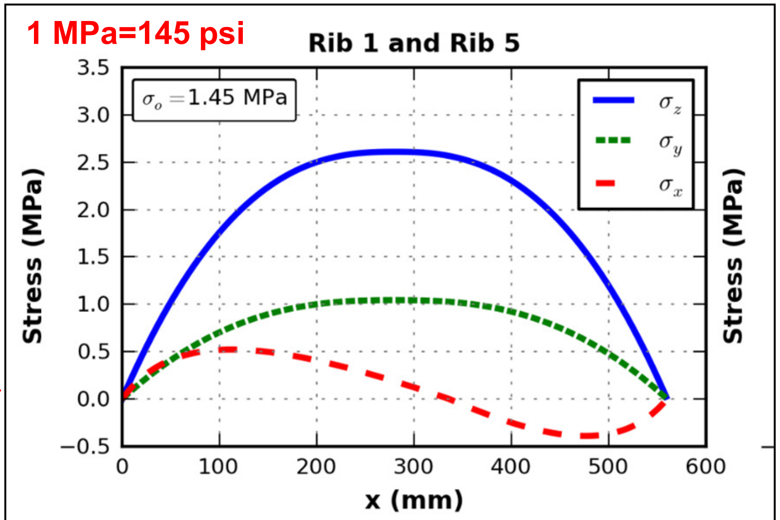
Load 262.1 kN

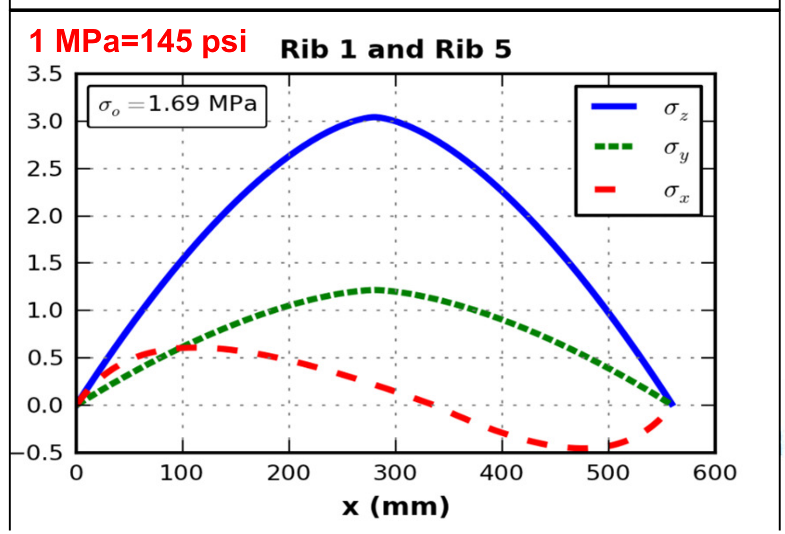


- Tire footprint



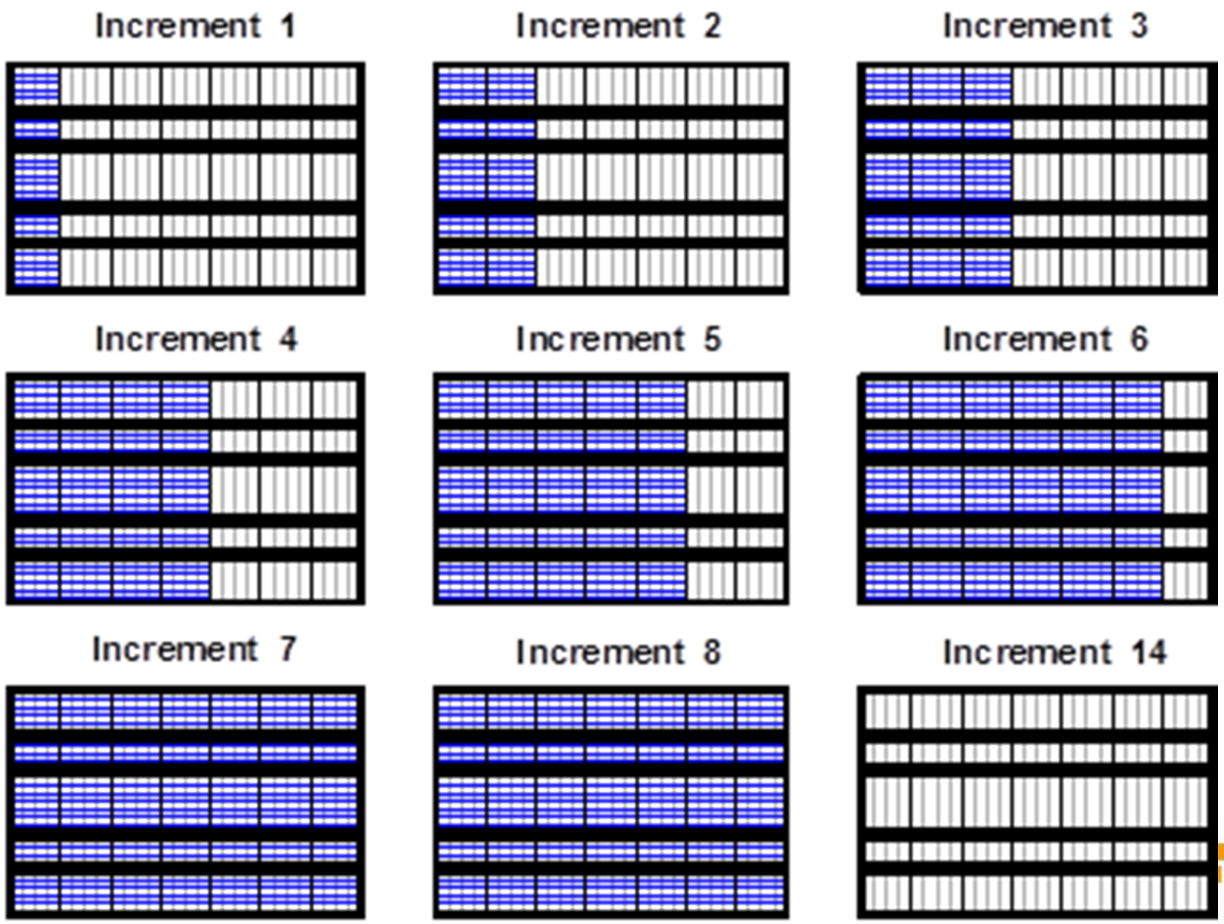
- 3D contact stresses



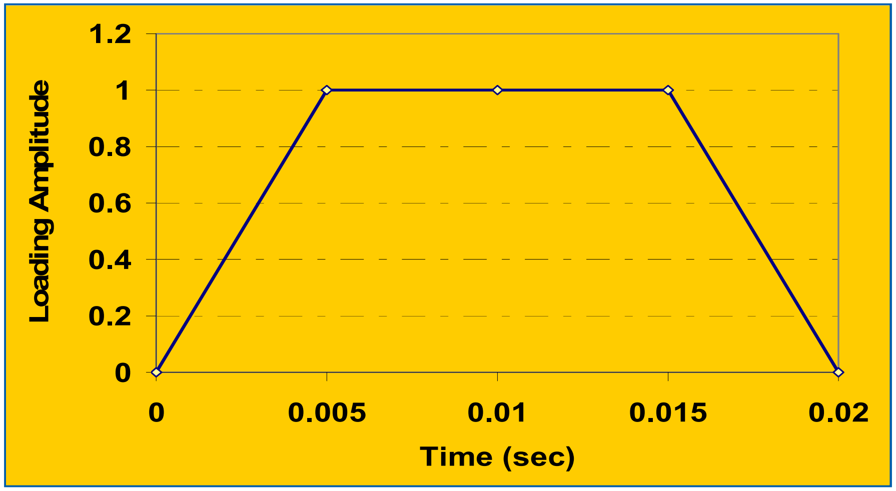


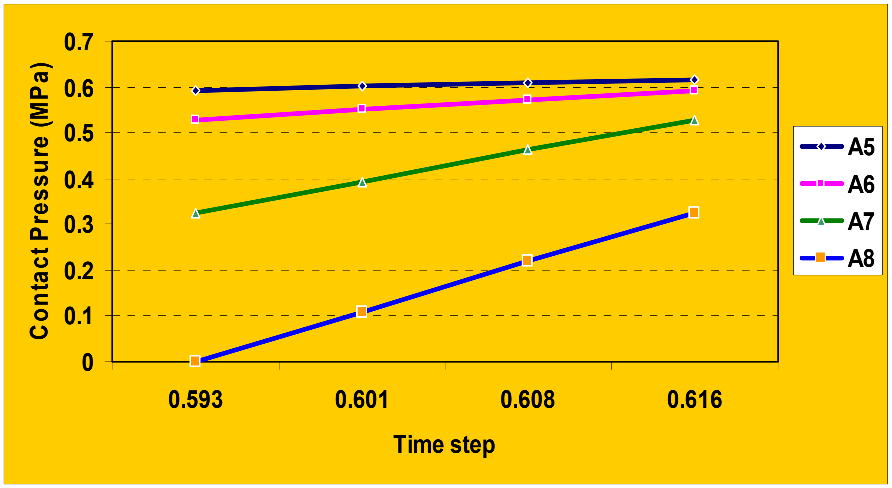
Takeoff

- Contact patch gradually loaded

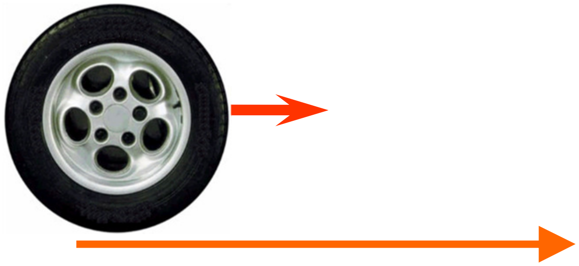


Continuous Moving Loading

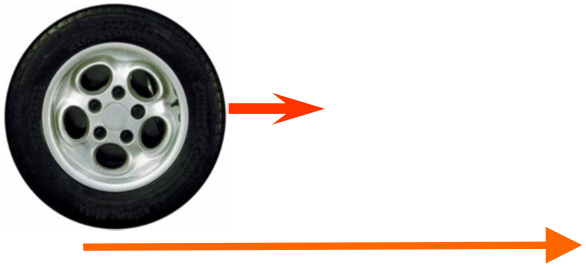




Trapezoidal



Continuous



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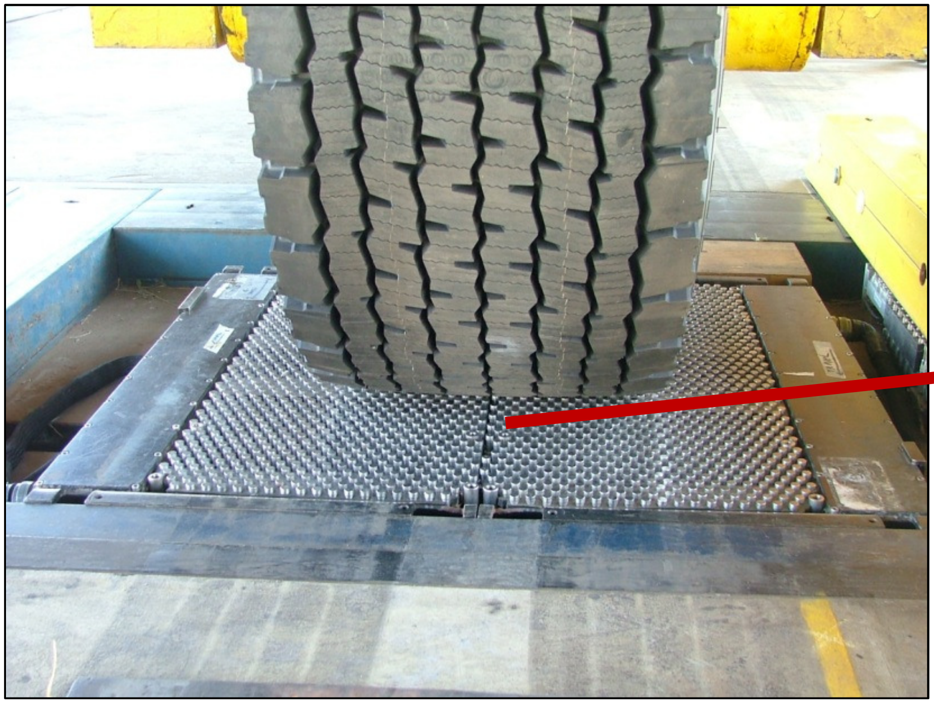
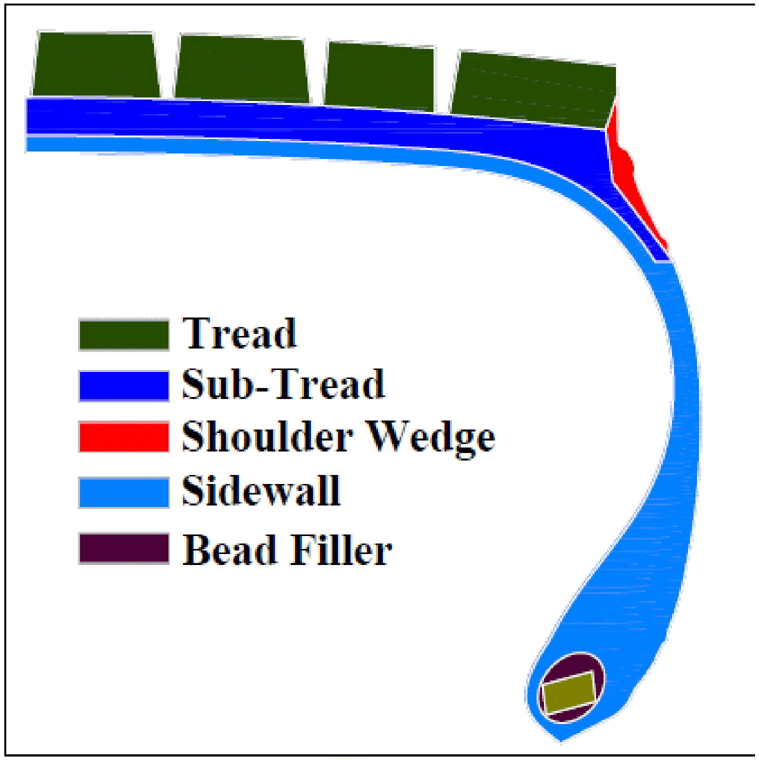
Measurement Contact Stresses



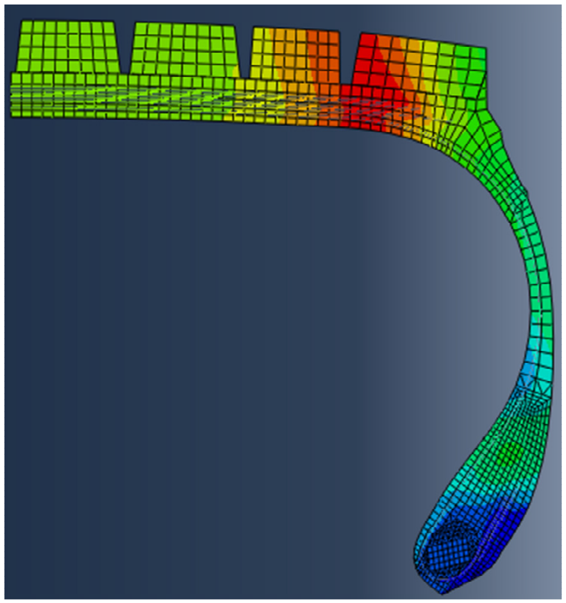
Tire Modeling

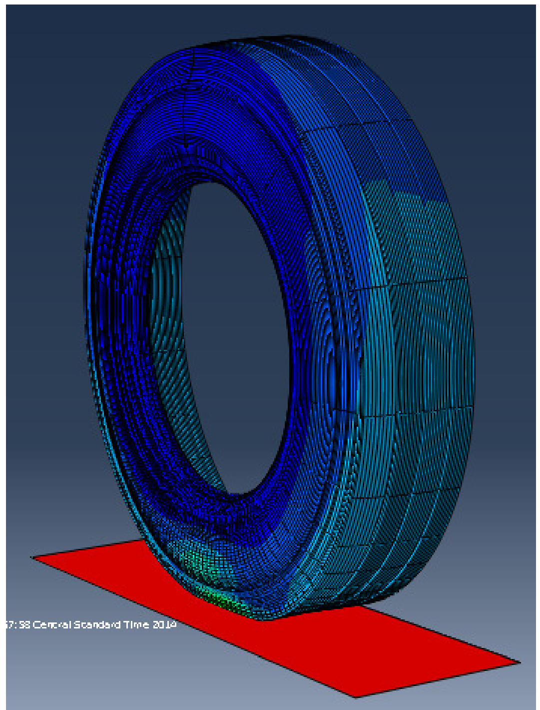
- Measuring contact stresses is cumbersome and expensive
- Simplified methods needed: modeling and analytical expressions
- Tire components: Rubber and Reinforcement

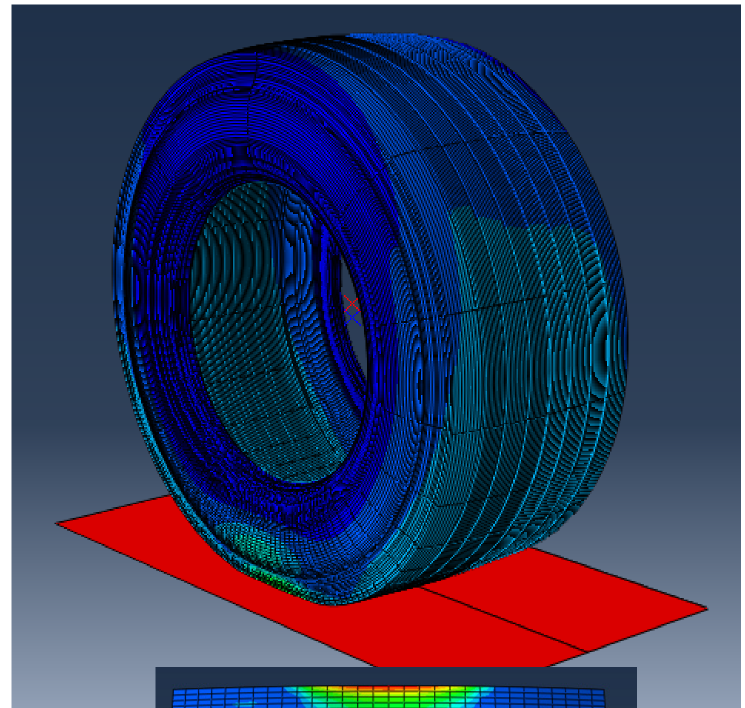


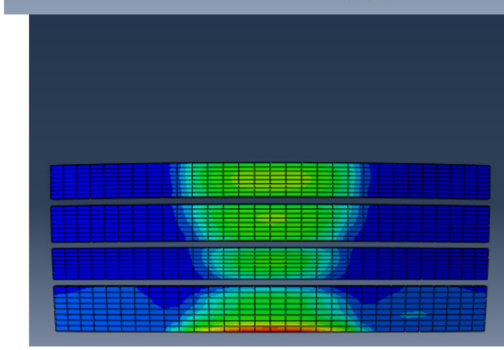
Tire Modeling

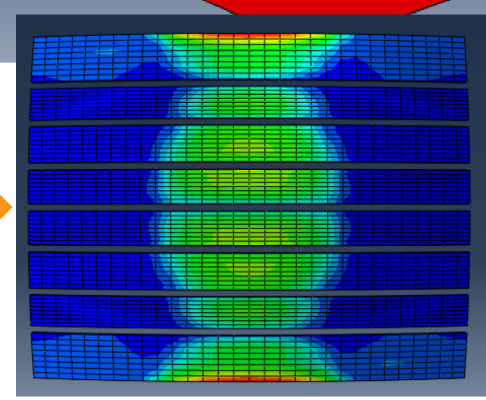
Axisymmetric | **Half Tire** | **Full Tire**



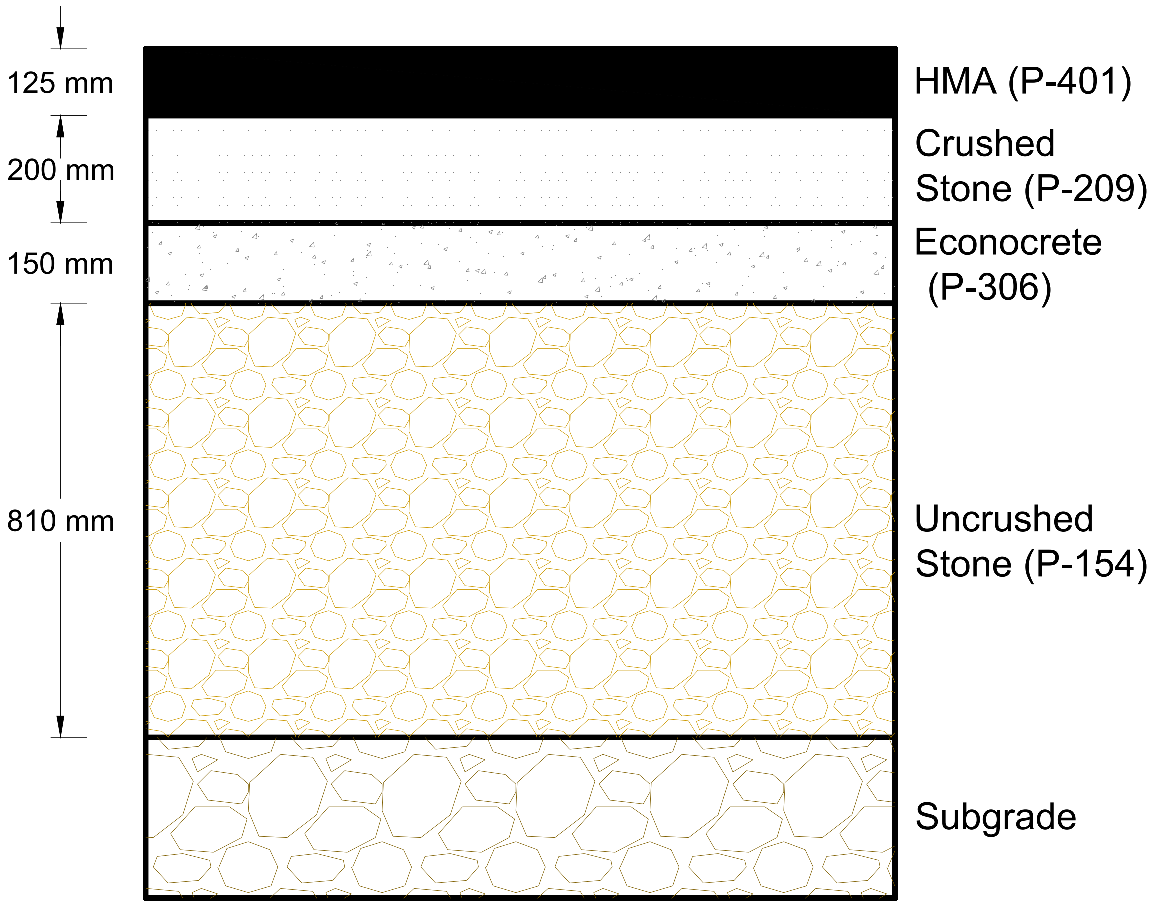








Numerical Modeling NAPTF Section



Elastic Modulus for linear elastic analysis

Layer	E (MPa)
AC (P-401)	3151.0
Base (P-209)	518.0
Econocrete (P-306)	4830.0
Uncrushed Stone (P-154)	276.0
Subgrade	36.0

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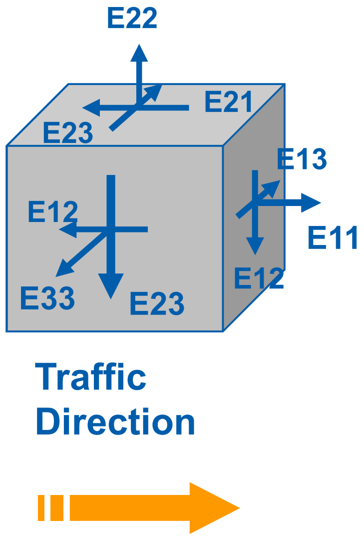
Responses Considered

$\varepsilon_{11,ac}$	Longitudinal tensile strain bottom of AC
$\varepsilon_{33,ac}$	Transverse tensile strain bottom of AC
$\varepsilon_{22,bs}$	Vertical strain base
$\varepsilon_{22,sg}$	Vertical strain subgrade
$\varepsilon_{23,ac}$	Vertical shear AC
$\varepsilon_{23,bs}$	Vertical shear base
$\varepsilon_{23,sg}$	Vertical shear subgrade



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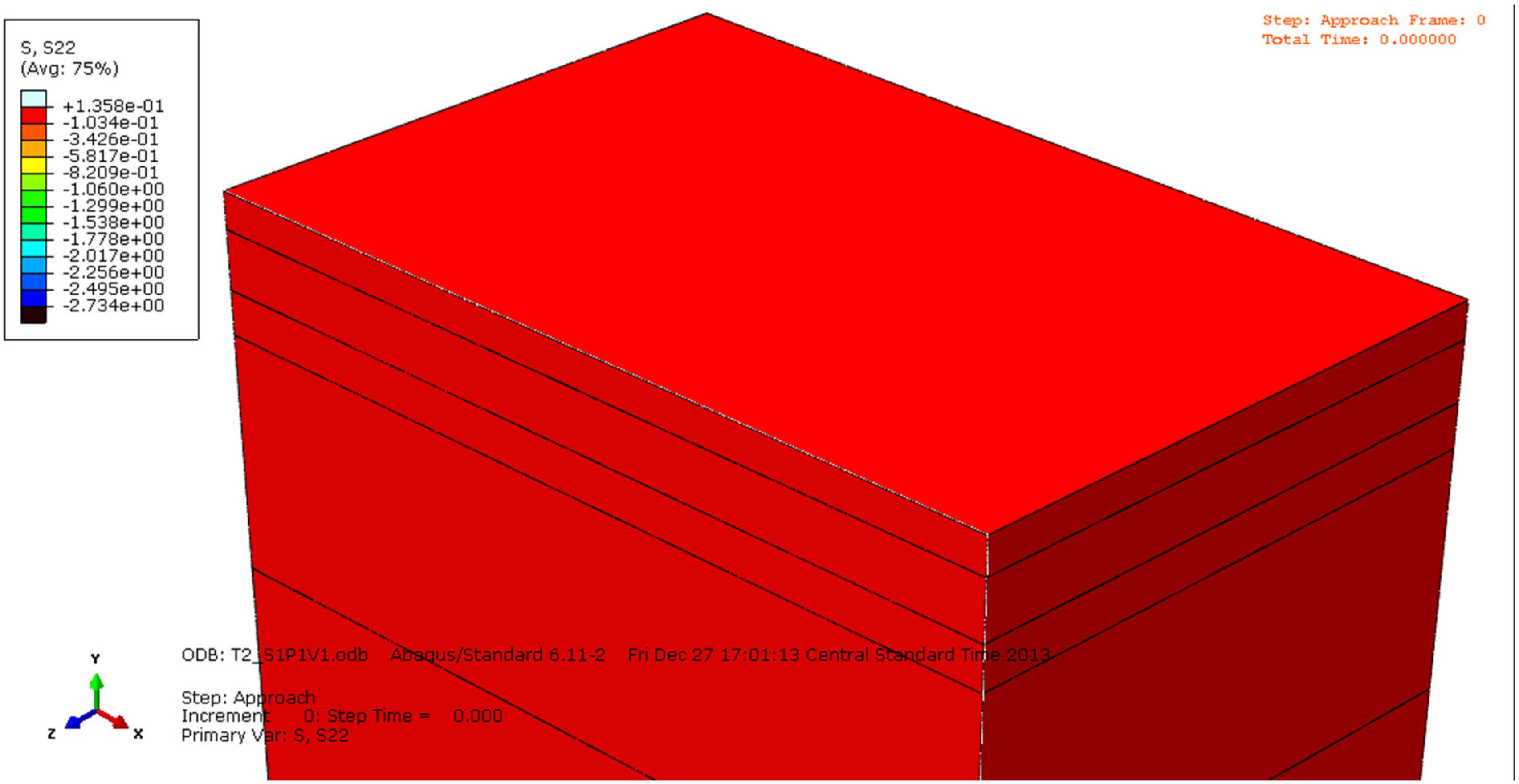
Conventional vs FEM

	WinJULEA	3D FEM	Diff. (%)
$\varepsilon_{11,ac}$	377.8	480.2	27.1
$\varepsilon_{33,ac}$	377.8	495.3	31.1
$\varepsilon_{22,bs}$	1893.7	3052.8	61.2
$\varepsilon_{22,sg}$	547.9	557.0	1.7
$\varepsilon_{23,ac}$	196.5	200.1	1.8
$\varepsilon_{23,bs}$	734.4	350.3	-52.3
$\varepsilon_{23,sg}$	189.6	108.5	-42.8

Modeling Results



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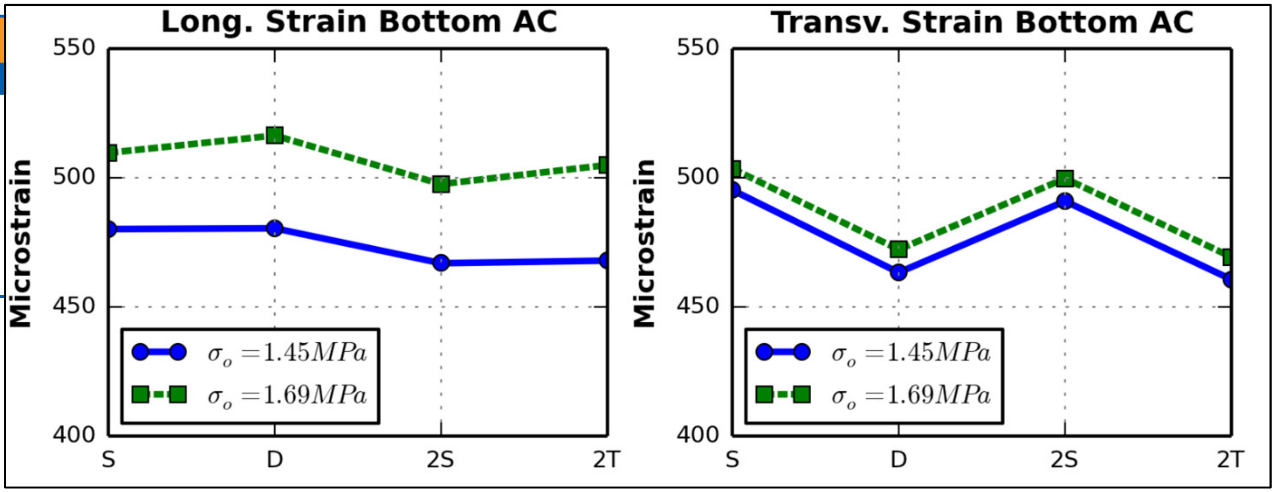
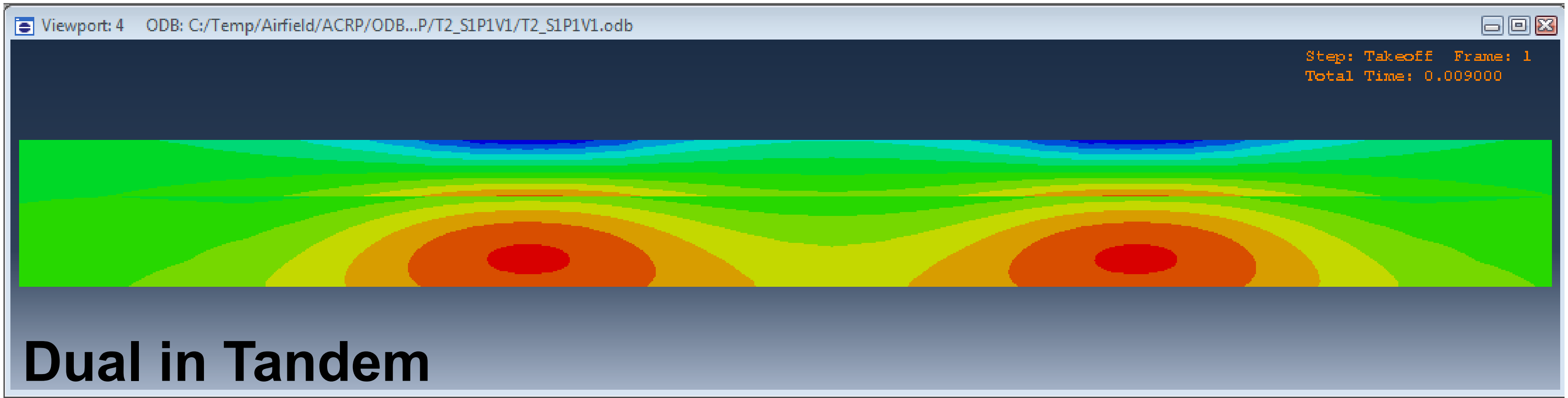
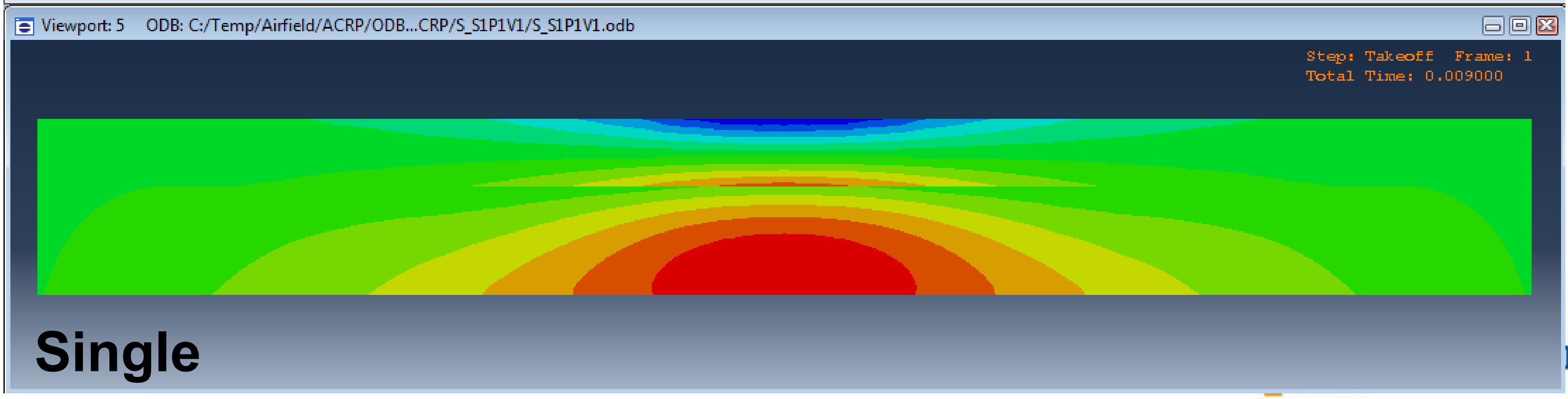
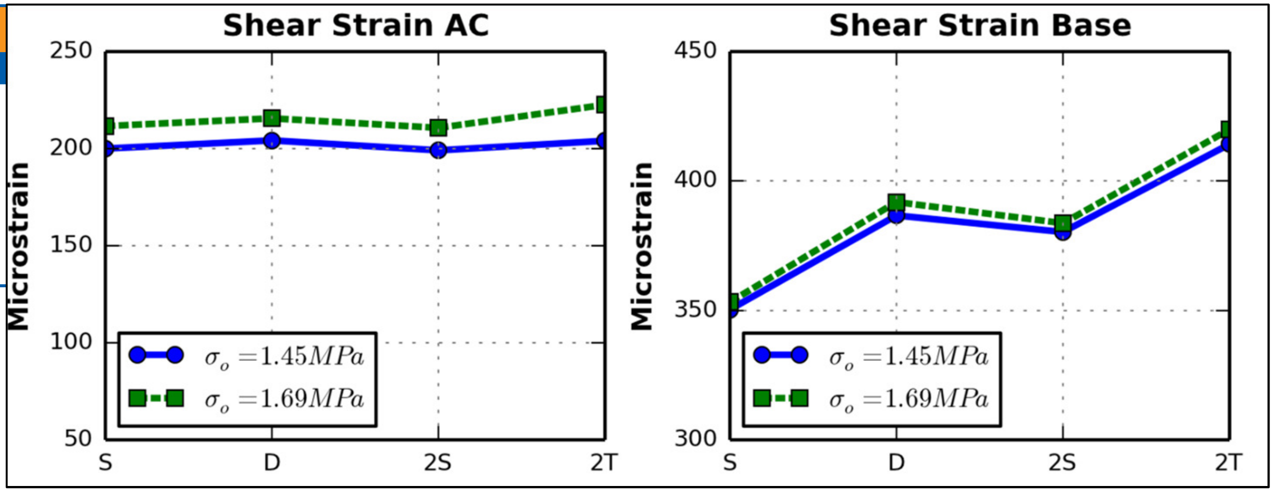
Strain at Bottom of AC

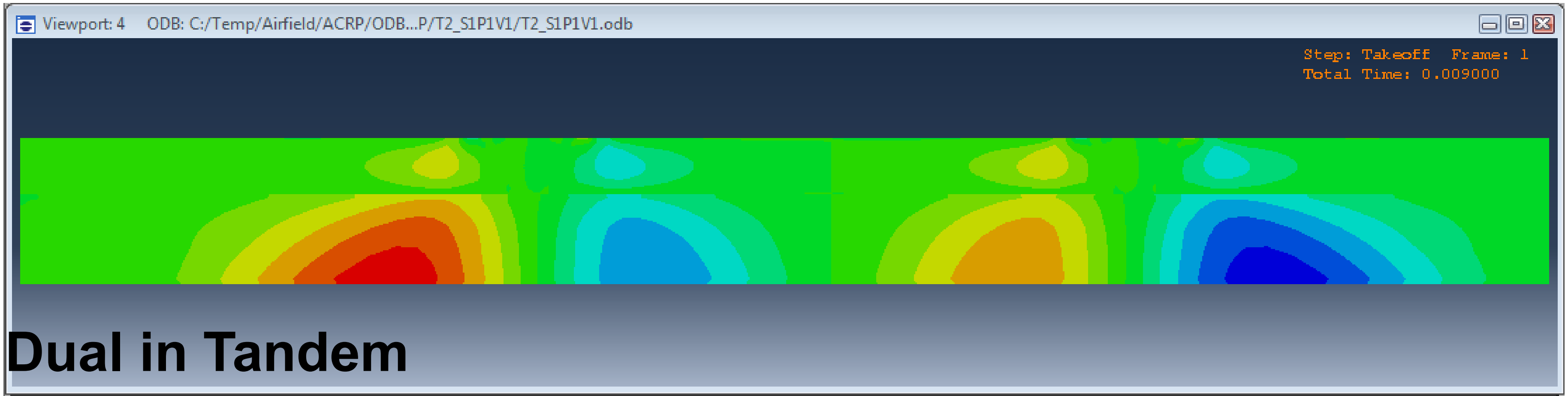


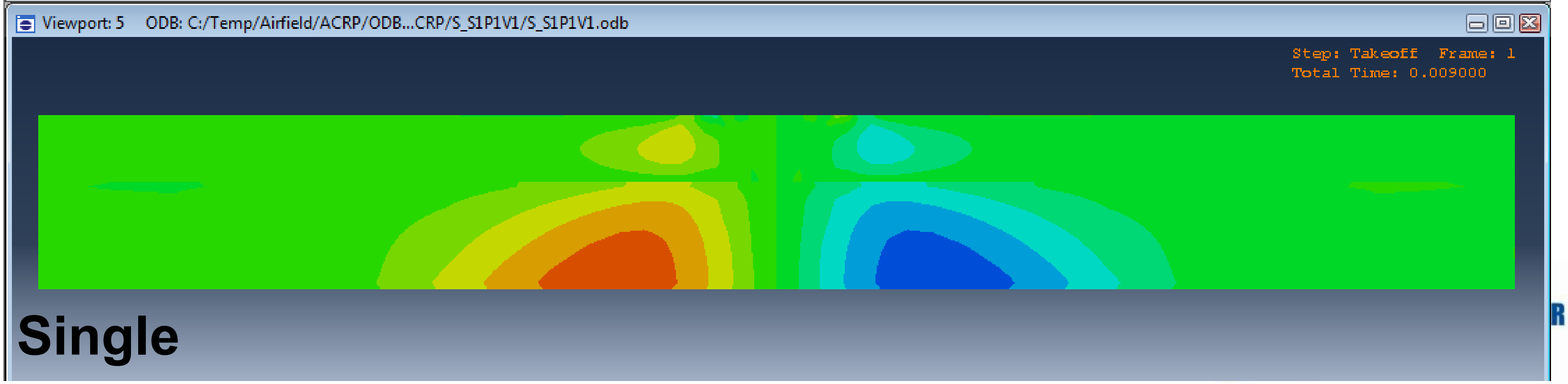




Shear Strain

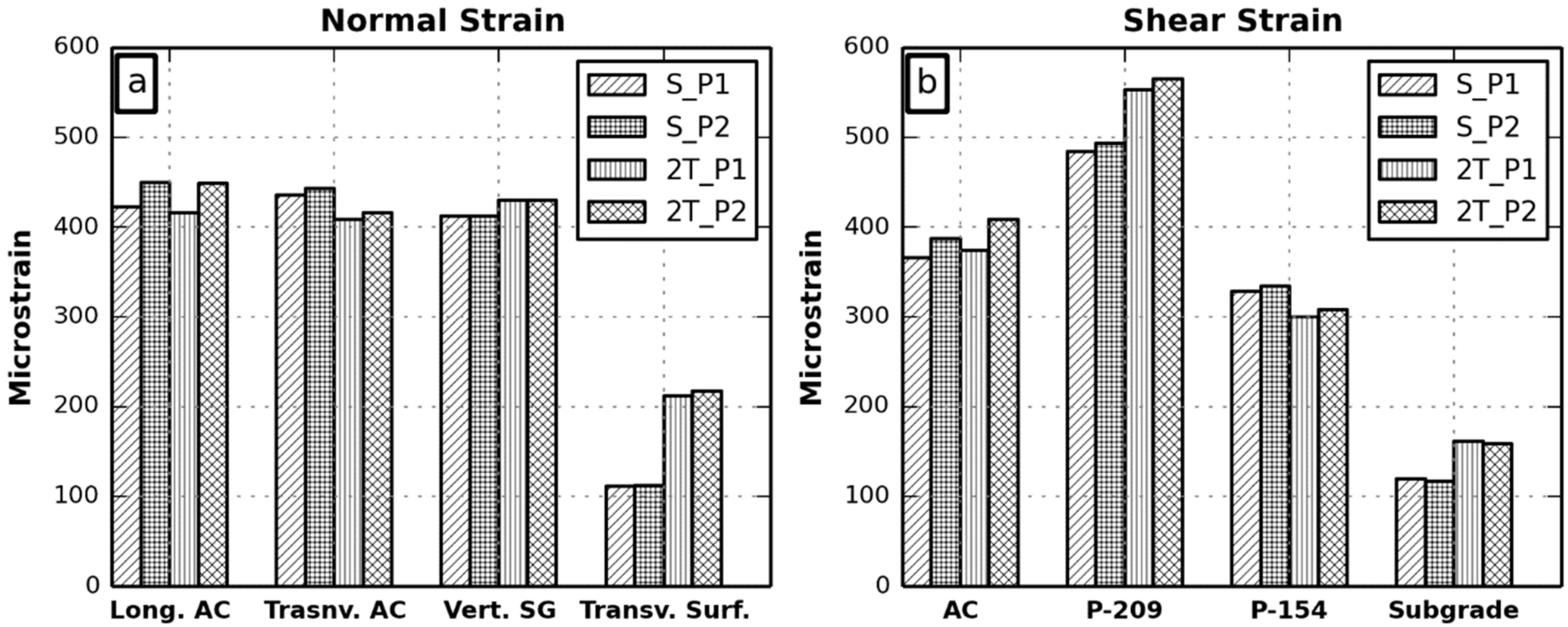






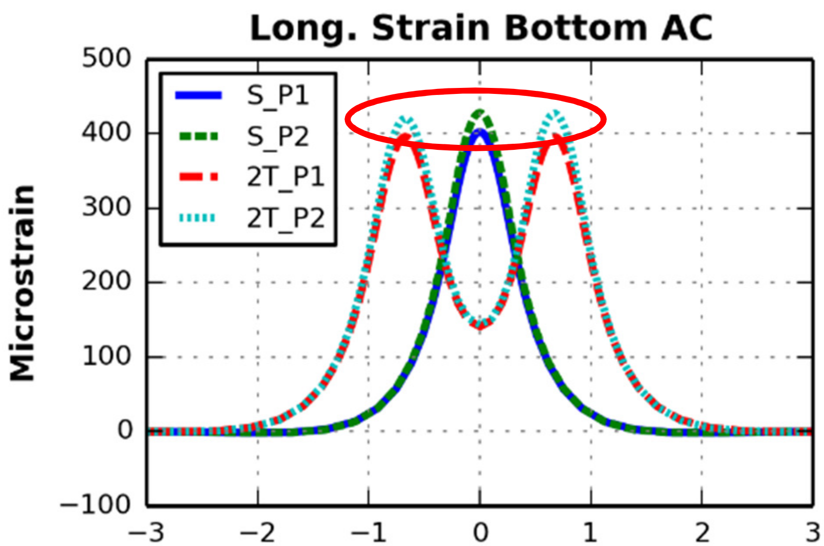
Gear and Inflation Pressure Effect

- **Gear configuration** mainly affected $\varepsilon_{33.surf}$ and $\varepsilon_{23.sg}$
- **Inflation pressure** relevant for $\varepsilon_{11,ac}$

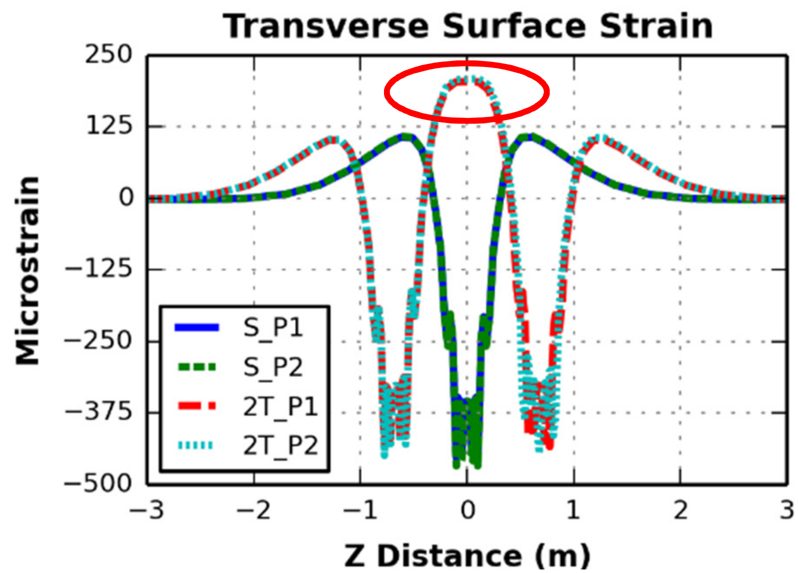


S=Single, 2T: Dual in tandem; P1=1.45 MPa; and P2=1.69 MPa

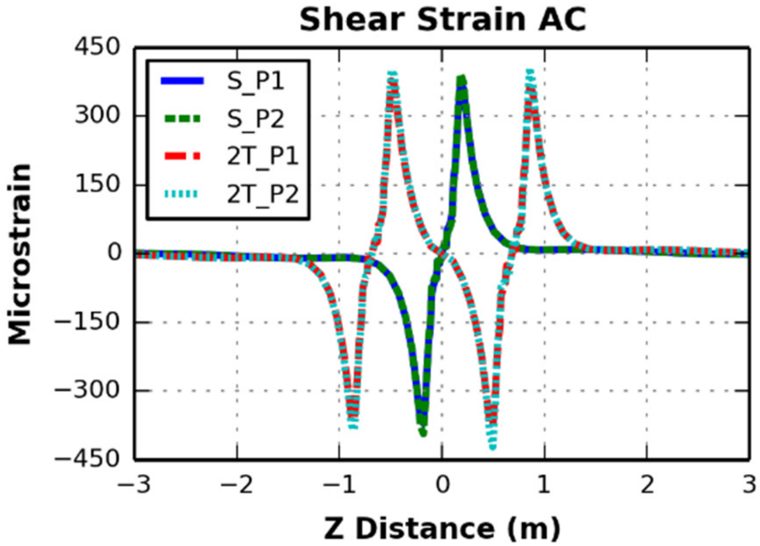
Transverse Variation Normal Strains

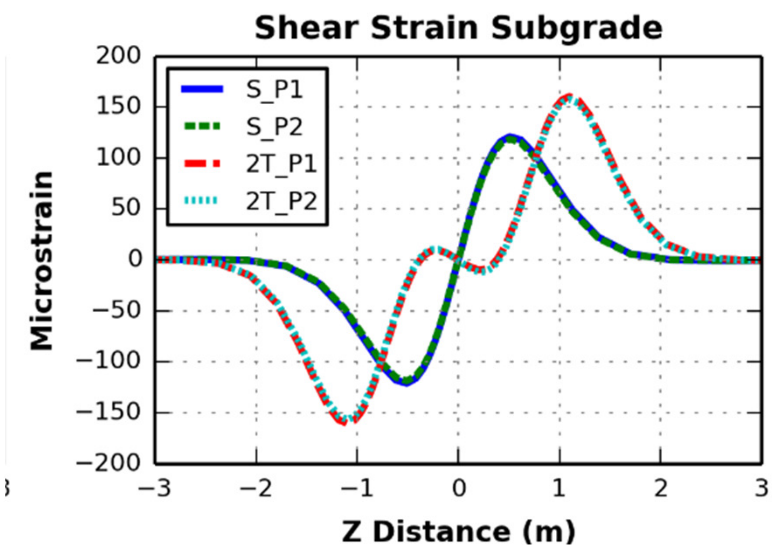


- Maximum $\varepsilon_{11,ac}$ located under a tire, then low influence of gear configuration but higher effect of inflation pressure
- Similar behavior for $\varepsilon_{22,sg}$ and ε_{33ac}
- Maximum $\varepsilon_{33,surf}$ next to tire, then high influence of gear configuration



Transverse Variation Shear Strains





- In AC, shear strain was mainly affected by inflation pressure
- Location of maximum shear departs from tire's edge as depth increased
- Shear strain in subgrade was greatly influenced by gear configuration

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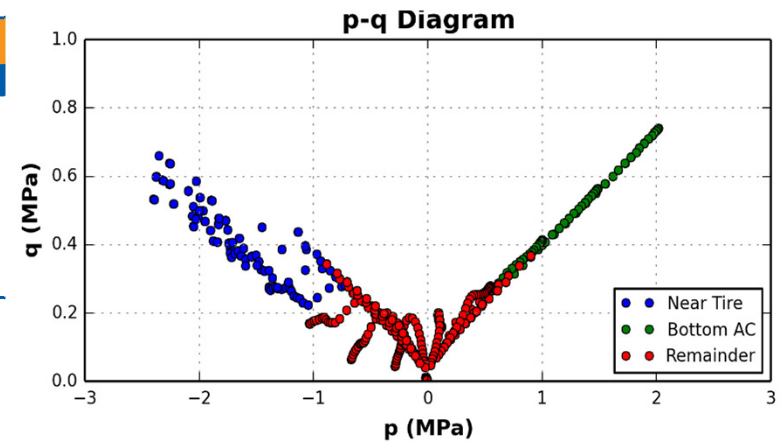
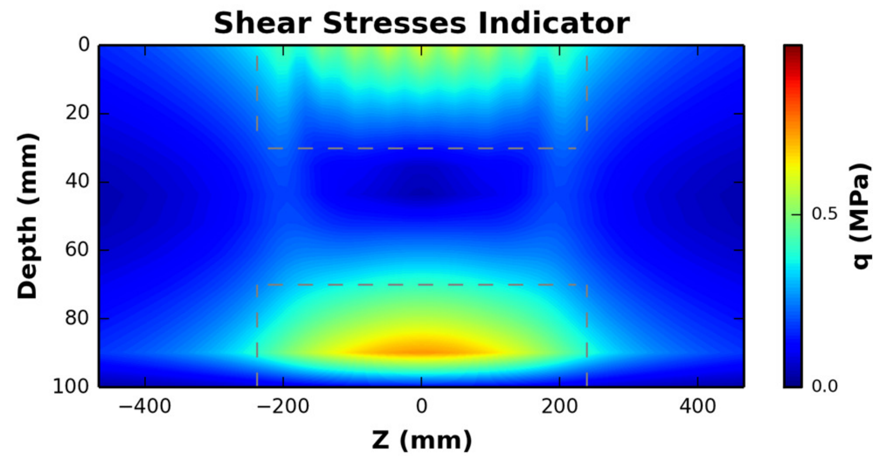
Combined Stress Indicators

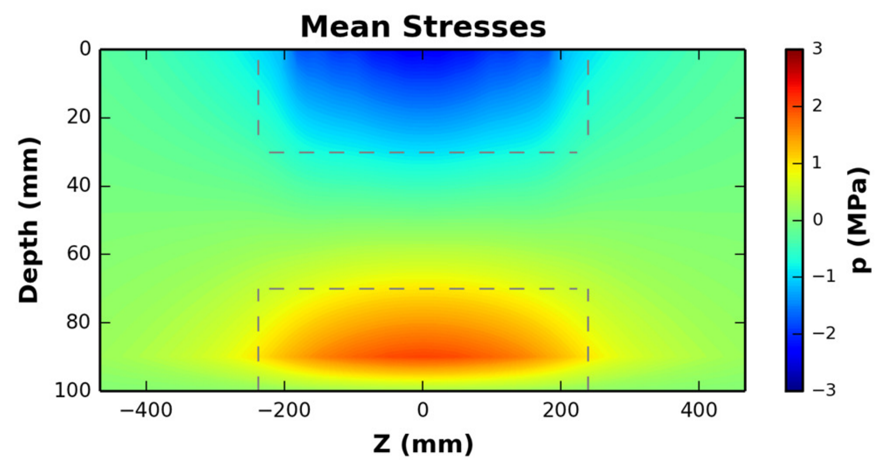
- **3D stresses** state provided better understanding of structural behavior
- **Isolated responses** (e.g. ε_{11}) cannot capture near-surface differences
- **Zone close to tire and at bottom of AC** are critical

$$p = \frac{1}{3}(\sigma_1 + \sigma_2 + \sigma_3);$$

$$q = \frac{1}{6}\sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_1 - \sigma_2)^2 + (\sigma_1 - \sigma_2)^2}$$







Final Remarks

- Conventional pavement analysis has significant limitations
- Analysis of airfield pavement should not be limited to tensile strain at bottom of AC and vertical strain on top of subgrade
- Gear configuration is relevant for transverse surface strain and shear strain in base and subgrade
- Tire inflation pressure mainly affected responses under the top 10 in

Future Work

- Model validation through airfield pavement instrumentation
- Model contact stresses at the tire-pavement interface
- Analysis of combined stress/strain indicators (e.g. octahedral shear stresses, mean stresses)
- Development of simplified tool to replace FEM (e.g. Artificial Neural Networks)

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- Navneet Garg of FAA Airport Technology R&D

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QUESTIONS?